CHAPTER 4

PROTECTIVE BEACHES AND DUNES

4-l. Protective Beaches.

a. General.

(1) The sloping beach and beach berm are the outer line of defense in absorbing most wave energy; dunes are the last zone of defense in absorbing the energy of storm waves that overtop the berm. Beaches and dunes form a natural system of shore protection for coastal lowlands and associated development. When the natural protection system provides inadequate protection from large storms, the first solutions frequently chosen are quasi-natural methods such as beach nourishment or artificial sand-dune construction. Such solutions retain the beach as a very effective wave energy dissipater and the dune as a flexible last line of defense. Poorly conceived construction involving removal of berms and dunes or changes in long shore transport often aggravate shoreline erosion within and adjacent to the project area.

(2) Beach sediments on most beaches range from fine sands to cobbles. The size and character of sediments and the slope of the beach are related to the forces to which the beach is exposed and the type of material available on the coast. Much of the beach material originates many miles inland where weathering of mountains produces small rock fragments that are reduced to sand and gravel. When this sand and gravel reaches the coastal area, it is moved along shore by waves and currents. This longshore transport is a constant process, and great volumes may be transported. Beach material is also derived from erosion of nearby coastal beaches and dunes caused by waves and currents and, in some cases, by onshore movement of sediment from deeper water. In some regions, a sizable fraction of the beach material is composed of marine shell fragments, coral reef fragments, cobbles, or volcanic materials. Clay and silt do not usually exist on ocean beaches because the waves create such turbulence in the water along the shore that these fine particles are suspended and transported to low energy areas, either offshore into deeper water or into bays and estuaries.

(3) Beach characteristics are usually described in terms of average size of the sand particles that make up the beach, range and distribution of sizes of the sand particles, sand composition, elevation and width of berm, slope or steepness of the foreshore, the existence (or lack) of an offshore bar, and the general slope of the inshore zone fronting the beach (Figure 4-l). Generally, the larger the sand particles the steeper the beach slope. Beaches with gently sloping foreshores and inshore zones usually have a preponderance of the finer sizes of sand.

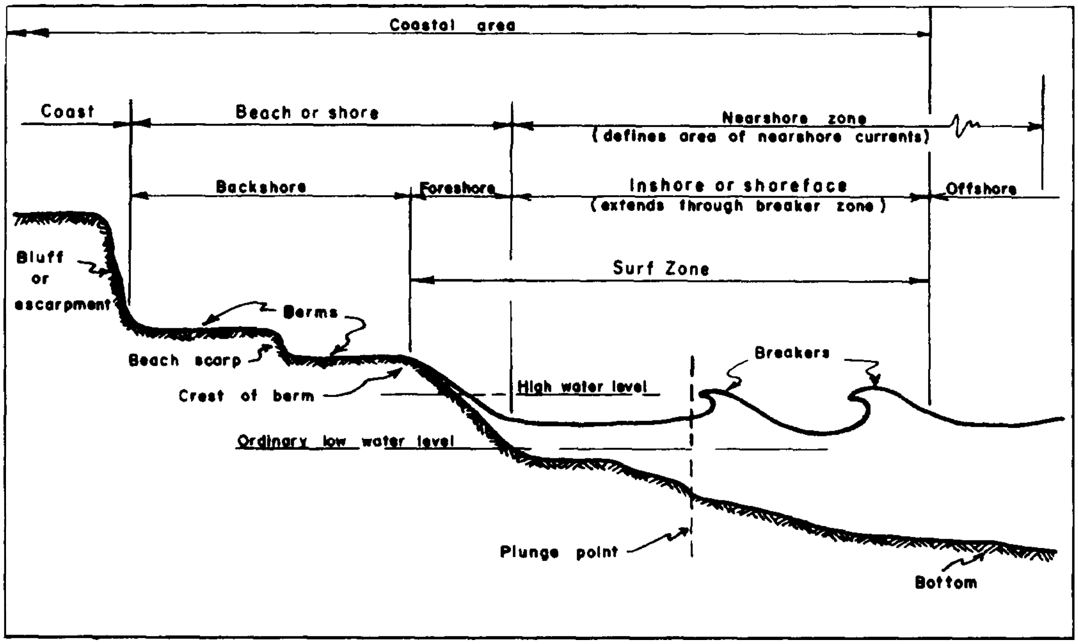

Figure 4-1. Visual definition of terms describing a typical beach profile (US Army Engineer Waterways Experiment Station 1984)

(4) Beaches can effectively dissipate wave energy and are classified as shore protection structures when maintained at proper dimensions. When beaches have narrowed because of long-term erosional trends or severe storms, beach restoration is often proposed. Beach restoration is the practice of mechanically or hydraulically placing sand directly on an eroding shore. However, it is important to remember that the replenishment of sand eroded from the beach does not in itself solve an ongoing erosion problem. Periodic replenishment will usually be required. Replenishment along an eroding beach segment can also be achieved by stockpiling suitable beach material at its updrift end feeder beach and allowing longshore processes to redistribute the material along the remaining beach. The establishment and periodic replenishment of such a stockpile is termed "artificial beach nourishment" (Figure 4-2). Artificial beach nourishment then maintains the shoreline at its restored position. When conditions are suitable for artificial nourishment, long reaches of shore may be protected by this method at a relatively low cost per linear meter of protected shore. An equally important advantage is that artificial nourishment directly but temporarily remedies a basic cause of most erosion problems--a deficiency in sand supply--and benefits rather than damages the adjacent shore. However, the use of feeder beaches may not be applicable in all cases. Thus, nourishment may be required along the entire length of an eroded beach. Feeder beaches are most often used after a beach has been restored to an acceptable alignment.

b. Role in Shore Protection. The shoreline, the interface between the land and the sea, is located where tides, winds, and waves attack the land, and where the land responds to this attack by a variety of "give and take" measures which effectively dissipate the sea's energy.

Figure 4-2. Beach nourishment operation, Mayport, Florida (courtesy of US Army Engineer District, Jacksonville)

(1) As a wave moves toward shore, it encounters the first beach defense in the form of the sloping nearshore bottom (Figure 4-3; Profile A). Along a gently sloping beach, when the wave reaches a water depth equal to about 1.3 times the wave height, the wave collapses or breaks. Thus, a wave 0.9 meter (3 feet) high will break in a depth of about 1.2 meters (4 feet). If there Is an increase in the incoming wave energy, the beach adjusts its profile to facilitate the dissipation of the additional energy. This adjustment is most frequently done by the seaward transport of beach material to an area where the bottom water velocities are sufficiently reduced to cause sediment deposition. Eventually enough material is deposited to form an offshore bar that causes the waves to break farther seaward, widening the surf zone over which the remaining energy must be dissipated. Tides compound the dynamic beach response by constantly changing the elevation at which the water intersects the shore and by providing tidal currents. Thus, the beach is always adjusting to changes in both wave energy and water level.

(2) During storms, strong winds generate high, steep waves. In addition, these winds often create a storm surge which raises the water level and exposes higher parts of the beach to wave action. The storm surge allows the large waves to pass over an offshore bar or reef formation without breaking. When the waves finally break, the remaining width of the surf zone is not sufficient to dissipate the increased energy contained in the storm waves. The remaining energy is spent in erosion of the beach, berm, and sometimes dunes which are now exposed to wave attack by virtue of the storm surge. The eroded

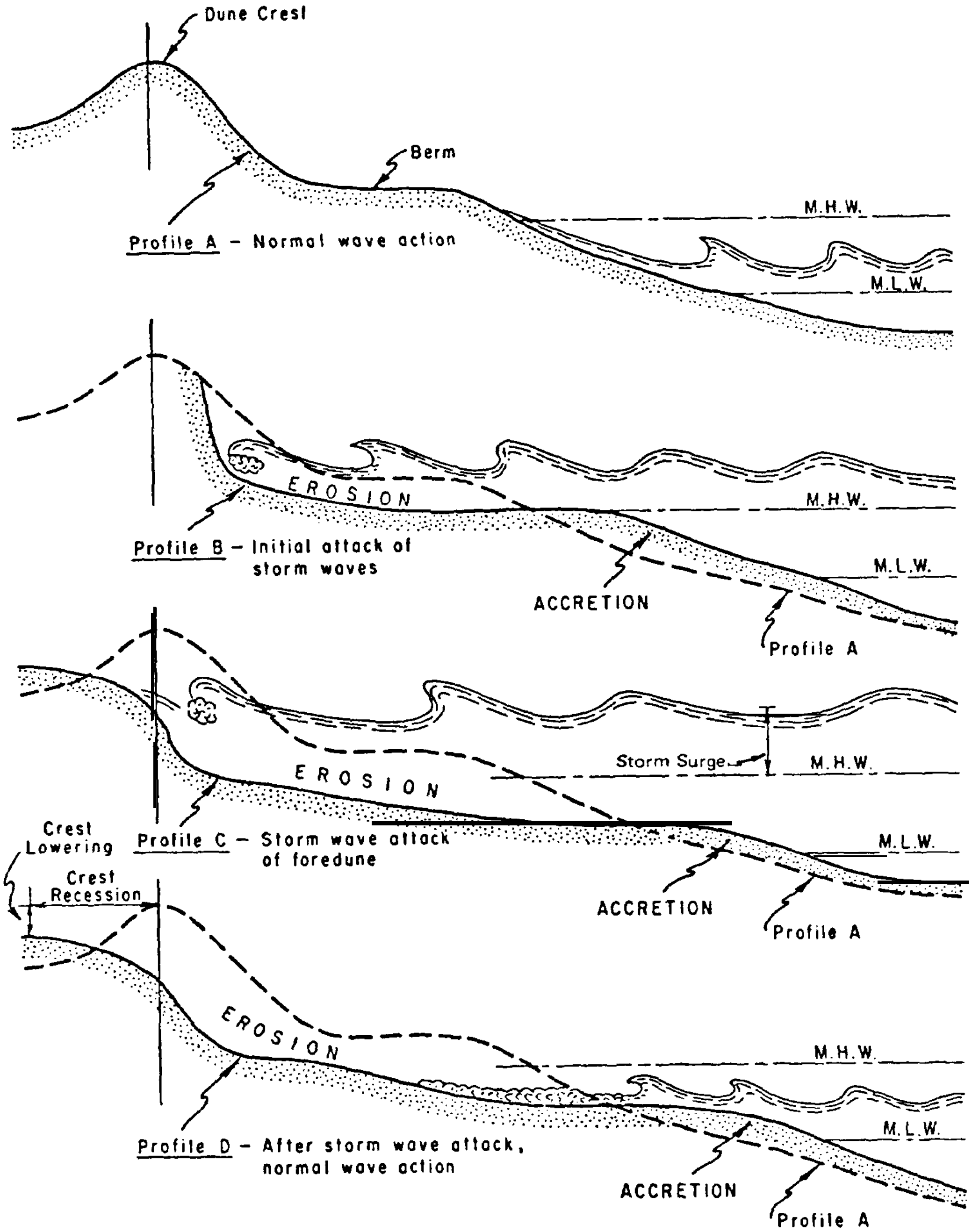

Figure 4-3. Schematic diagram of storm wave attack on beach and dune

material is carriedoffshore in large quantities where it is deposited on the nearshore bottom to form an offshore bar. This bar eventually grows large enough to break the incoming waves farther offshore, forcing the waves to spend their energy in the surf zone. This process is illustrated in Figure 4-3 (Profiles B, C, and D).

(3) Beach berms are built naturally by waves to about the highest elevation reached by average storm waves. When storm waves erode the berm and carry the sand off shore, the protective value of the berm is reduced and large waves can overtop the berm. The width of the berm at the time of a storm thus influences the amount of damage a storm can inflict. During extreme events, berm material can be carried landward and deposited, thus removing the material from the zone of littoral drift.

(4) Another dynamic feature of the beach and nearshore physical system is littoral transport, defined as the movement of sediments in the nearshore zone by waves and currents. Littoral transport is divided into two general classes : transport parallel to the shore (longshore transport), and transport perpendicular to the shore (onshore-offshore transport). The material that is transported is called littoral drift. Longshore transport results from the stirring up of sediment by the breaking waves and movement of this sediment by a longshore current generated by the breaking waves. The direction of longshore transport is directly related to the angle at which the wave breaks relative to the shoreline. Onshore-offshore transport is determined primarily by wave steepness, sediment size, and beach slope. In general, high steep waves move material offshore, and low waves of long period (low steepness) move material onshore.

C. Physical Considerations.

(1) Construction impacts.

(a) Three primary methods of placing sand on an eroding beach are land-hauling from a nearby borrow area, direct pumping of sand through a pipeline from an inlet or an offshore borrow area using a floating dredge, and transporting sand in a split-hull barge from a nearby area. Two basic types of floating dredges are used to remove material from the bottom and pump onto the beach. These two are the hopper dredge (with punp-out capability) and the hydraulic pipeline dredge (suction dredge). Hydraulic pipeline dredges are better suited to sheltered waters where wave height is less than one meter. A cutterhead is often used on the suction dredge. The action of the cutterhead agitates the substrate to a greater degree than a suction dredge without a cutterhead, creating a greater potential for elevated suspended sediment concentrations and turbidity. However, suspended sediments and turbidity are generally not a problem in sands. Studies have shown that very little material is resuspended from a properly operated cutterhead dredge. Desilting or sedimentationbasins are often needed to provide a controlled environment where pipeline slurry waters can be pumped and dewatered prior to placement of sand on the beach. These basins prevent the ecological and esthetic consequences of turbidity and sedimentation from pipeline discharges.

(b) Placement of equipment such as dredge anchors and pipelines can damage environmentally sensitive habitats such as coral reefs, seagrass beds, and dunes. Damage to coral reefs has been caused by dragging of anchors or other equipment across a reef (Maragos et al. 1977, Spadoni 1979, Courtenay et al. 1980). In addition, the operation of equipment on the beach can damage dune vegetation and may cause compaction. Narrow-tracked vehicles do not distribute the weight of the equipment as well as wider tracked vehicles and cause greater damage to the vegetation and increased sand compaction. Highly compacted beaches may have reduced numbers of burrowing organisms. Beach borrowing animals such as ghost crabs and sea turtles have difficulty digging in compacted beaches.

(2) Sediment modification.

(a) Sediments on most beaches range from fine sands to cobbles. The size and character of sediments and the slope of the beach are related to the natural forces to which the beach is exposed and the type of sediment available on the coast. The beach sediments may be in equilibrium due to the prevailing physical forces, or they may be eroding or accreting. When material is newly deposited on a high-energy beach, it modifies the beach sand/water interface and generally sand grain-size distribution, and may increase the suspended sediments of the adjacent nearshore waters depending on the type and particle size of sediments deposited. Waves and currents tend to winnow the finer sediments and to suspend them in the water column. Finer sediments are transported offshore and are deposited in the deeper, calmer offshore waters. These processes continue at a rather rapid pace until a more stable (flatter) beach profile is again achieved. Parr et al. (1978) observed at Imperial Beach, California, that fine sediments were rapidly sorted out of nourishment sediments and that sediment grain-size distribution after about four months was comparable to the beach sediments prior to nourishment. Generally, silts and clays in the fill material are suspended during placement, but after initial placement turbidity and suspended sediments are dissipated.

(b) Coincident with changes in grain size and shape in beach material, an increase in compaction of the beach can result from beach nourishment. A compact beach is less suitable for burrowing organisms. An increase in fine material, mineralization or the binding together of particles, and the layering of flat-shaped grains may contribute to an increase in compaction. However, a greater occurrence of increased compaction is likely when sand is pumped onto a beach in a water slurry. This sand-water slurry allows maximum crowding together of sand grains which results in a very dense, compact beach (Smith 1985). Increases in compaction may be a short-term effect since the beach will be softened by wave action, particularly during storms.

d. Water Quality Considerations. Problems related to water quality and turbidity in the nearshore zone of a high-energy beach do not appear to be a major concern because the fine sediments that contain high levels of organic material and other constituents are rapidly transported offshore and sulfides are oxidized (Naqvi and Pullen 1982). However, high turbidities resulting from prolonged beach nourishment and/or erosion degradation of nourishment material may indirectly affect light-sensitive plants and animals. The reduced sunlight penetration into the water may impact nearshore corals, associated algae, and submerged aquatic vegetation. It may also affect the migration and feeding of visually oriented adult and juvenile fishes and the recruitment of larval and juvenile animals to the beaches. Turbidity resulting from beach nourishment generally creates only minor impacts in the surf and the offshore zones except when light sensitive resources are involved (Naqvi and Pullen, 1982). Precautions should be taken to use only clean, uncontaminated material. While most dredged material is clean sand, concerns about the presence of toxins in the borrow material will have to be addressed.

e. Biological Considerations.

(1) Fish and other motile animals.

(a) Suspended solids in the water can affect fish populations by delaying the hatching time of fish eggs (Schubel and Wang 1973), killing the fish by abrading their gills, and anoxia (O'Connor et al. 1976). Fish tolerance to suspended solids varies from species to species and by age (Boehmer and Sleight 1975, O'Connor et al. 1976). This problem does not appear to be a major one along coastal beaches.

(b) Destruction of habitat rather than suspension of sediments seems to be the major hazard to beach and nearshore fishes. Most of these animals have the ability to migrate from an undesirable environment and return when disposal ceases (O'Connor et al. 1976, Courtenay et al. 1980). Species that are closely associated with the beach for part of their life cycle are most likely affected by beach nourishment. Parr et al. (1978) observed that beach nourishment did not prevent subsequent spawning of grunion (Leuresthes tenuis) at Imperial Beach, California. However, the dusky jawfish (Opistognathus whitehursti), a burrowing species with limited mobility and narrow sand grain-size requirements, was displaced by fine sediments on the east coast of Florida (Courtenay et al. 1980).

(c) The loss of a food source due to burial by nourishment sediments may also have some effect on motile populations. However, there is evidence that nourishment benefits some fish by suspending food material (Courtenay et al. 1972). Also, associated turbidities may provide temporary protection from predators (Harper 1973). Studies indicate that fishes may be attracted to dredging (Ingle 1952, Viosca 1958) or to sand mining operations (Maragos et al. 1977). Sherk et al. (1974) found that demersal fishes are more tolerant to suspended solids than filter-feeding fishes.

(d) Several long-term studies have shown that moderate to complete recovery of motile animal populations occurred within less than a year. Courtenay et al. (1972, 1980), Parr et al. (1978), Reilly and Bellis (1978), and Holland et al. (1980) described motile fauna recovery following beach nourishment. These studies have shown that motile animals generally temporarily depart an area disturbed by beach nourishment, but return when the physical disturbance ceased. Oliver et al. (1977) observed that demersal fishes moved into an area within the first day after a disturbance. Courtenay et al. (1980) noted that lobsters, crabs, shrimp, and fishes left disturbed areas, but reappeared within four months after the disturbance. The motile animals which have stringent environmental requirements, such as substrate preferences for spawning, foraging, or shelter, are most likely to be affected.

(2) Benthos.

(a) Species comprising marine bottom communities on most high-energy coastal beaches are adapted to periodic changes related to the natural erosion and accretion cycles and storms. Organisms adapted to unstable nearshore bottom conditions tend to tolerate perturbations better than those in more stable offshore environments (Thompson 1973, Oliver and Slattery 1976). Burial of offshore benthic animals by nourishment material has a greater potential for adverse impacts because the subtidal organisms are more sensitive to perturbation than those in the intertidal and upper beach zone (Naqvi and Pullen 1982). For that matter, any project which results in net deposition of sediment onto an offshore benthic community will tend to cause greater impacts. Direct burial of nonmotile forms with beach nourishment material can be lethal, whereas motile animals might escape injury. However, burial of animals is not generally significant at the population or community level, unless it is a sensitive resource such as corals. Some infaunal bivalves and crustaceans can migrate vertically through more than 0.3 meter (1 foot) of sediment (Maurer et al. 1978). Survival depends not only on the depth of deposited sediment, but also on rate of deposition, length of burial time, season, particle-size distribution, and other habitat requirements of the animals.

(b) Following dredging and burial of benthic animals, a short-term increase in diversity, accounted for by recruitment of opportunistic species, may occur (Clark 1969, Gustafson 1972, Parr et al. 1978, Applied Biology, Inc. 1979). These opportunistic species, which initially invade the disturbed area, are generally later replaced by species common to the original community. A similar response can also result from natural events such as storms, hurricanes, and episodes of "red tide" organisms (Saloman and Naughton 1977, Simon and Dauer 1977). The recovery rate of preproject resident species will vary from 5 weeks to 2 years (Hayden and Dolan 1974, Saloman 1974, Parr et al. 1978, Reilly and Bellis 1978, Taylor Biological Company 1978, Tropical Biological Industries 1979, Marsh et al. 1980). Reef corals tend to be among the slowest of recolonizers (15-50 years) and usually require hard substrates for larval settlement and attachment.

(c) Recovery will depend on the species affected, the season in which nourishment occurs, and the recruitment of larvae into the area. The ability of most macrofauna to recover rapidly is due to their short life cycles, their high reproductive potential, and the rapid recruitment of planktonic larvae and motile macrofauna from nearby unaffected areas. Shore zone animals are generally adapted to living in a high-energy environment; thus they can tolerate a high level of disturbance.

(3) Oysters. The turbidity and increased sedimentation that can result from beach nourishment in coastal bays and estuaries can be detrimental to oysters. Elevated turbidity can reduce oyster respiration and ingestion of food (Loosanoff 1962). Mature oyster reefs are more susceptible to elevated turbidity, sedimentation, and direct physical alteration than immature reefs because mature reefs are already stressed from crowding (Bahr and Lanier 1981). Even a moderate disturbance of a mature reef can destroy it. Immature reefs can undergo rapid growth and thus are more resilient to disturbance (Bahr and Lanier 1981).

(4) Seagrasses and mangroves. Burial, uprooting, elevated turbidity effects, and sedimentation as results of beach nourishment may damage coastal vegetation (Zieman 1982). Seagrasses may be slow to recover when rhizomes are severed and plants are uprooted (Godcharles 1971, Zieman 1975). Elevated siltation rates and turbidity can cause suffocation and reduce photosynthetic activity in seagrasses (Thayer et al. 1984). Covering of mangrove prop roots with dredged material can kill the plants (Odum et al. 1982).

(5) Corals.

(a) Corals are sensitive to covering by fine sediments (Figure 4-4). Hard corals (Scleractinians) are more sensitive than soft corals (Octocoralians) because they are not as capable of cleansing themselves of heavy sediment loads and are easily smothered. Sand or silt accumulation on reefs will foul and kill corals, algae, other invertebrates, and also displace other resident invertebrates and fish. The soft corals are better adapted for survival in the nearshore areas subject to beach nourishment.

(b) Coral damage as a result of beach nourishment is usually caused by elevated sedimentation rates and by direct physical damage (e.g. burial) to the reef. Sedimentation may inhibit the food-acquiring capability of the coral polyps and inhibit photosynthesis of symbiotic unicellular algae (Zooanthellae), eventually killing the coral (Goldberg 1970, Courtenay et al. 1972).

(c) Several studies have shown that coral reefs can withstand some sedimentation. Courtenay et al. (1974) examined the effects of beach nourishment on nearshore reefs at Hallandale Beach, Florida. They noted that the reefs sustained short-term damage caused by fine materials eroding from the nourished beach. A follow-up survey seven year later found no evidence of major reef damage (Courtenay et al. 1980, Marsh et al. 1980). Excessive sedimentation which buries a reef results in permanent destruction or replacement by soft bottom habitat and communities. Even for reefs where accumulated sediment is removed by later storms, recolonization by corals and other organisms on the dead surfaces may take decades to be complete.

(6) Sea turtles.

(a) Nourishment can affect the sea turtles directly by nest burial or by disturbing nest locating and digging behavior during the spring and summer

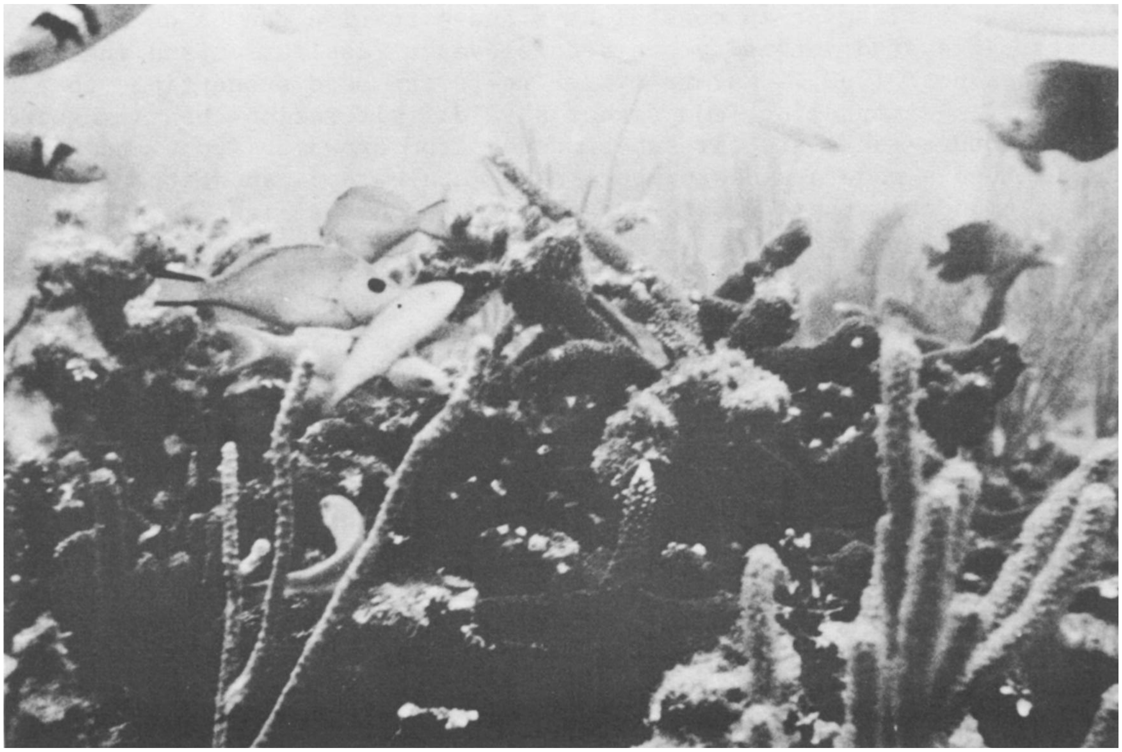

Figure 4-4. Reef fauna near outer edge of second reef off Golden Beach, Florida (Courtenay et al. 1980)

nesting season (Figure 4-5). Indirectly, beach nourishment or replenishment has the potential of affecting sea turtle nest site selection, egg clutch viability, and hatchling emergence by altering the physical makeup of the beach. Factors such as sand grain size distribution, grain shape, moisture content, color, temperature, and the density of the sand may be altered.

(b) Smaller grain size, flatter shaped grains, and greater density may cause compaction of the beach. A compacted beach will inhibit nest excavation by sea turtles (Fletemeyer 1980, Ehrhart and Raymond 1983) and impede emergence of hatchlings (Fletemeyer 1979). Mortimer (1981) and Schwartz (1982) reported that an optimum range of grain size for hatchling success was coarse to fine sand (2.5 to 0.125 millimeters). Even though sand particle size distribution varies greatly from one nesting beach to another (Hirth and Carr 1970, Hirth 1971, Hughes 1974, Stancyk and Ross 1978), when sands are too fine the gas diffusion rate required to support embryonic development may become inadequate (Ackerman 1977; Mortimer 1979, 1981; Schwartz 1982). If sands are too coarse, the nest collapses and the hatchling turtles are unable to emerge to the surface (Mann 1978, Sella 1981).

(c) Sand temperature may be affected by sand color, density, and grain size of borrow material. Nest site selection, incubation duration, sex ratio,

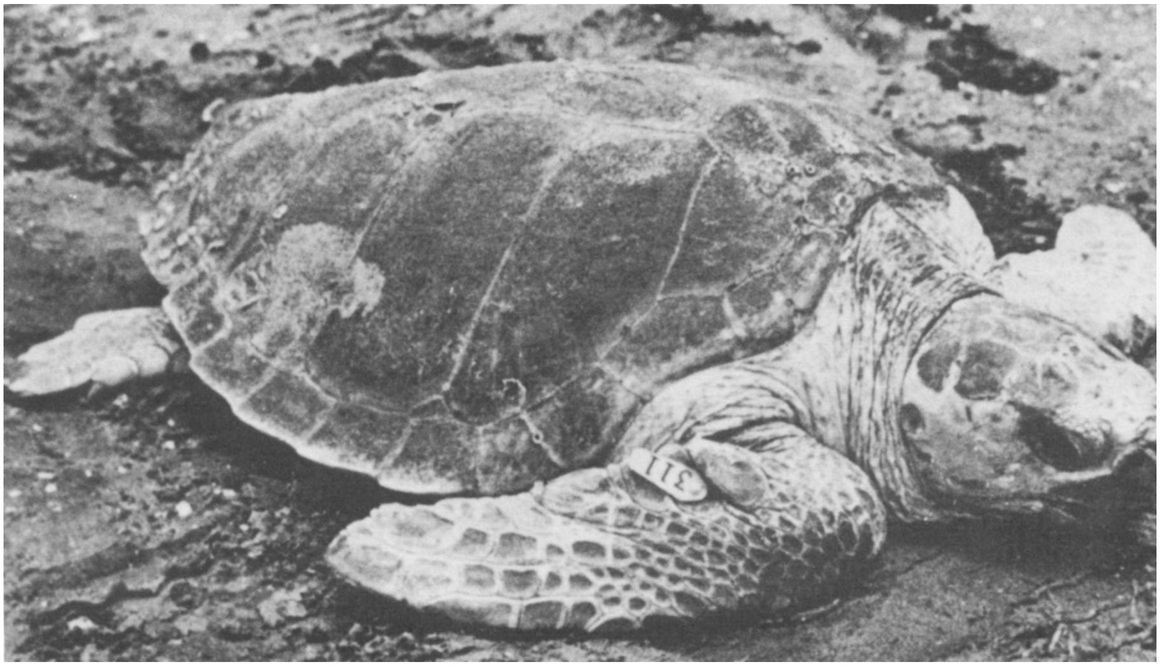

Figure 4-5. Nesting sea turtle

and hatchling emergence of turtles may be influenced by sand temperature (Mrosovsky 1980, 1982; Stoneburner and Richardson 1981). Stable nest temperature is a prerequisite for normal development of green and loggerhead turtles (Sella 1981, Geldiay et al. 1981). Lower ambient sand temperature increases incubation time (Harrison 1952, Hendrickson 1958, Mrosovsky 1982). Temperature is also an important determinant of hatchling sex ratios (Morreale et al. 1982). Incubation temperatures above 30" C result in more females hatchling, whereas below 30" C more males hatch (Yntema and Mrosovsky 1982). Morreale et al. (1982) also report that warmer temperatures inhibit emergence of hatchlings from the nest, presumably due to hatchlings cueing on cooler nighttime temperature6 for synchronization of nocturnal emergence.

(d) Sand moisture content may be affected by grain size, grain shape, pore space, compaction, density, and other factors. Moisture content can in turn affect hatching success of sea turtles (Ackerman 1977, Mortimer 1981). Too much moisture may decrease gas diffusion to the nest because of waterlogging of the sand (Ackerman 1977), while too little moisture may cause higher nest temperatures and egg desiccation (Mortimer 1981).

f. Recreational Considerations.

(1) Beach restoration and nourishment usually produce tangible recreation benefits by increasing the dry beach area. In general, the dry beach area determines the potential carrying capacity of the beach. Although there is no current formally established standard in the United States, EM 1110-1-400 recommends 50 square feet (4.6 square meters) of dry beach and 30 square

feet (2.8 square meters) of swimming area per bather as peak carrying capacity for optimal beach usage benefits (Figure 4-6). However, in resort area6 with many visitor6 and limited beaches, densities may be much higher.

Figure 4-6. Recreational use of Delray Beach, Florida

(2) To the coastal engineer the dry beach is the "backshore" which consists of the "natural berm" and "storm berm." Increasing the width of the berm region is an important design criterion in beach restoration projects. Criteria for specifying berm width depend on several factors. If the purpose of the fill is to restore an eroded beach to protect backshore improvements from major storm damage, the width of the berm may be determined as the protective width of historical record which has been lost during storms plus the minimum required to prevent wave action from reaching improvements. Where the beach is used for recreation, the optimum width of the beach may be influenced by the recreational use. Estimated beach use is generally based on the prospective change6 in population of the area6 considered tributary to the beach and the beach-carrying capacity and availability of alternative sites. Federal participation in beach erosion control projects is limited to a part of the construction costs for restoration and protection of beach fills, based on public ownership and use of the shore frontage. For these projects, other recreation developments are entirely non-Federal responsibilities except on Federally owned shore6 (ER 1165-2-130).

g. Aesthetic Considerations.

(1) The alignment of a nourished beach segment generally parallel6 the existing shoreline but is offset seaward by the width of the fill. The

nourished segment can be thought of as a subtle headland that protrudes from the existing coast. Transition from the fill to the existing shoreline can be accomplished either by constructing 'hard' structures, such as groins and jetties, or by filling transition zones between the terminal ends of the beach fill and the unrestored beach. The use of containment structures often produces an abrupt transition at the limits of the project, and the structures themselves detract from the natural appearance of the beach. When transition fill is used in lieu of structural containment, the nourished beach is gradually merged with the natural shore and visual impacts are lessened or may be absent altogether. The orientation of the transition shoreline will differ from the natural shoreline alignment; however, for engineering reasons this difference is usually quite small.

(2) Locating borrow material that is visually compatible with the natural beach is often impractical and ha6 generally not proven to be a necessary practice from the standpoint of aesthetics. Borrow sediments containing organic material or large amounts of the finer sand fraction have been used as beach fill since natural sorting and winnowing processes clean the fill material. This fact ha6 been confirmed with fills containing fine sediments at Anaheim Bay and Imperial Beach, California, and Palm Beach, Florida. Also fill material darkened by organic material (Surfside and Sunset Beach, California) have been bleached quickly by the sun to achieve a more natural beach color. However, coastal engineers attempt to locate borrow materials that are texturally compatible with the natural beach. Textural properties of native sand are selected for the comparison because their distribution reflects a state of dynamic equilibrium between sediments and processes within the system. This process frequently leads to the selection of visually compatible borrow material (US Army Engineer Waterway6 Experiment Station 1984).

h. Cultural Considerations. As a shore protection measure, beach restoration will potentially protect onsite cultural resources. However, impacts on cultural site6 associated with increased beach use and the impact of beach induced recreational or commercial development should be evaluated, In addition, when beach restoration is confined by "hard" structures, the impact of these structures on erosion rates in adjacent areas and possible erosion of cultural resources should be considered.

i. Environmental Summary.

(1) Environmental design.

(a) Equipment. A suction dredge with a cutterhead is less desirable than a dredge without a cutterhead for extracting beach nourishment material in the vicinity of live coral reefs or other light sensitive resources (Courtenay et al. 1975, Maragos et al. 1977). The suction dredge without a cutterhead is generally desirable because siltation is minimized and there is less potential for physical damage to the reef. To prevent sand compaction, wide-tracked vehicle6 should be used for moving equipment and beach nourishment material on the beach.

(b) Borrow material. The composition of sediment at the borrow sites should closely match that of the natural beach sediments (Thompson 1973, Parr et al. 1978, Pearson and Riggs 1981) and should be low in pollutants, silts, and clays. Minimum damage to the beach animals will occur when clean sand is placed on a sandy substratum. The damage may be great to the beach fauna if fine organic-rich sediments are used. In addition, fine sands exhibit greater density and thus greater potential for compaction. The vertical migration of infaunal animals may be inhibited when the particle size and composition of borrowed material differ from the original beach sediments (Maurer et al. 1978). To minimize siltation and consequently potential anoxic conditions following beach nourishment, the percentage of fine-grained sediments (smaller than 125 micrometers) should be kept to a minimum in the borrow material (Parr et al. 1978). Silt, which may be highly detrimental to corals and other beach and offshore benthic invertebrates, will be readily moved offshore if present in the material. Sedimentation can result in the reduction of species diversity. If a key specie (i.e., coral, seagrass, etc.) is affected adversely, the entire animal community of the area may be altered. Silt curtains may be used for containing silty sediments during construction. Silt curtains are not however, recommended for use in open water or in currents exceeding 1 knot. They are not effective for use in areas exposed to high winds or breaking waves or for preventing long-term elevated turbidity when silt is present in the material.

(c) Material placement. Nourishment material placed within the upper beach and the nearshore zone (intertidal) is best from an environmental standpoint. Organisms adapted to unstable nearshore bottom conditions tend to survive perturbations better than those in more stable offshore environments (Thompson 1973, Oliver and Slattery 1976). Burial of offshore benthic animals by nourishment material has a greater potential for adverse impacts because the subtidal organisms are more sensitive to perturbation than those in the intertidal and upper beach zone (Naqvi and Pullen 1982). In addition, by placing material into the intertidal portion of the beach, two benefits can be achieved. First, the maximum amount of existing beach is preserved. Second, the material is sorted and reworked by wave action, which reduces compaction.

(d) Time of placement. Most studies indicate that the optimal time for beach nourishment from a biological standpoint is during the winter (Saloman 1974, Oliver and Slattery 1976, Reilly and Bellis 1978, US Army Corps of Engineers 1979). Winter is typically the period of lowest biological activity. The spawning season for most nearshore and beach fauna occurs between the spring and fall. During winter adults have usually migrated out of the nearshore area and would be less concentrated in the shallow beach zone. Along most coasts, winter also has the most severe wave climate. This season makes it difficult to operate dredging equipment. It also may result in initial movement of large quantities of material offshore from the severe wave conditions.

(2) Environmental considerations. Though beach nourishment may be one of the most environmentally desirable and cost-effective shore protection alternatives, it is not without environmental consequences.

(a) Short-term impacts. During construction, the placement of equipment such as dredge anchors and pipelines can damage nearshore habitats and onshore earth-moving equipment can damage coastal vegetation. The dredging of material from the borrow area may cause locally elevated turbidity levels and increased sedimentation. However, few turbidity and sedimentation problems have ever been documented at the dredge cutterhead. Turbidity may impact motile animals while sedimentation can produce smothering of benthic fauna. The process of placing material on the beach will impact beach fauna. For a period following material placement, nearshore turbidity will be elevated because of the resuspension of fine sediments in the borrow material. The magnitude and duration of these impacts can be minimized through equipment selection, borrow material selection, the timing of construction, placement methods, and the use of dewatering, sedimentation or desilting basins.

(b) Long-term impacts. In general, beach restoration produces long-term recreational benefits and is seldom associated with long-term negative ecological impacts. Within a period of months, nourished beaches often visually and ecologically resemble undisturbed beaches. Potential long-term impacts are usually associated with sensitive habitats such as coral reefs and sea turtle nesting beaches. Under these circumstances special provision should be incorporated into the nourishment project to protect these resources. Many eroding shorelines do not provide sufficient surface area for nesting sea turtles. Restored beaches can provide additional nesting surface. Restored beaches require periodic replenishment. Therefore, impact assessments must consider that the short-term impacts will occur periodically over the life of the project. If a restored beach is confined by "hard" structures, the impact of these structures on the erosion rates in adjacent areas and possible erosion of cultural resources should be considered.

4-2. Dunes.

a. General.

(1) Foredunes are the dunes immediately behind the backshore. They are valuable, nonrigid shore protection structures created naturally by the combined action of sand, wind, and vegetation, often forming a continuous protective system.

(2) Dune building begins when an obstruction on the beach lowers wind velocity causing sand grains to deposit and accumulate. As the dune builds, it becomes a major obstacle to the landward movement of windblown sand. In this manner, the dune functions to conserve sand in the proximity to the beach system. Foredunes are often created and maintained by the action of the beachgrasses, which trap and stabilize sand blown from the beach.

(3) Foredunes may be destroyed by the waves and high-water levels associated with severe storms or by beach grass elimination (induced by drought, disease, excessive traffic by beach users, or overgrazing), which thereby permits local "blowouts." Foredune management has two divisions--stabilization and maintenance of naturally occurring dunes, and the creation and stabilization of protective dunes where they do not already exist.

(4) The creation of new barrier dunes or the rebuilding of damaged or incomplete foredunes may be done mechanically, by moving sand into place by truck, bulldozer, or pipeline dredge and grading it to suitable form, or by trapping blowing sand by means of sand fences or vegetation or a combination of these, where sand supply and wind pattern permit. The latter method utilizes natural forces to create dunes in the same way they develop in nature. It is usually the most economical method and tends to discourage the placement of dunes in unsuitable locations.

b. Beach Grasses For Beach and Dune Stabilization. The most common sand capture method is the use of dune vegetation, primarily beach grasses. Each coastal region has one or more beach grasses which are suitable for use in dune building. The most frequently used beach grasses are American beach grass (Ammophila breviligulata) along the mid-and upper-Atlantic coast and in the Great Lakes region: European beach grass (Ammophila arenaria) along the Pacific Northwest and California coasts; sea oats (Uniola paniculata) along the south Atlantic and Gulf coasts; and panic grasses (Panicum amarum) and (Panicum amarulum) along the Atlantic and Gulf coasts. Each of these grasses is easy to grow and plant, and all are efficient traps for sand. Stems of these plants are usually planted in early spring at one-half to one-meter (18- to 36-inch) centers in a band about 15 meters (50 feet) wide and parallel to the shore. If plantings are flooded with salt water during the growing season, the planting is usually destroyed. For this reason, a small elevated dune is often created prior to planting. Current dune construction methodology is described by Knutson (1977a-b) and Woodhouse (1978) and is summarized in the Shore Protection Manual (US Army Corps of Engineers 1984).

c. Other Herbaceous Vegetation for Beach and Dune Stabilization. There are a number of lesser known plant species that are very effective in stabilizing beaches and dunes. Some of these can be obtained commercially; however, most propagules of these species will be from such sources as donor beaches and sites. Grass species that can be effective in beach and dune stabilization include dune sandspur (Canchrus tribuloides), finger grasses (Chloris spp.), seaside paspalum (Paspalum vaginatum), coastal Bermuda grass (Cynodon dactylon), dropseeds (Sporobolus spp.), and others. Herbaceous plant species that can be effective for dune and beach stabilization include glass-worts (Salicornia spp.) which occur on all United States coasts, dune and beach morning glories (Ipomoea spp.), saltwort (Batis maritima), air potato (Dioscorea bulbifera), sea purslanes (Sesuvium spp.), pepper grass (Lepidum virginicum), lead plants (Amorpha spp.), water pennywort (Hydrocotyle bonariensis), seaside evening primroses (Oenothera spp.), false mallows (Sida spp.), common nightshade (Solanum americanum), sea oxeye (Borrichia frutescens), dog fennel (Eupatorium capillifolium), camphor weed (Heterotheca subaxillaris), and a number of others. Detailed information concerning these plants and their propagation can be obtained in Landin (1978), Coastal Zone Resources Division (1978), US Army Engineer Waterways Experiment Station (1978), and EM 1110-2-5026.

d. Woody Vegetation for Beach and Dune Stabilization.

(1) In addition to salt meadow cordgrass (Spartina patens) and other grasses and herbaceous plant species that can be used to stabilize beaches and dunes, there are a number of woody plant species that also can be used for this purpose. Stabilization can be achieved in tropical and semitropical areas where native woody species such as mangroves grow into the water. Mangroves help break up wave action on shorelines, while at the same time they trap sediment and speed up development of fast land along the shore. In the tropics, especially on low coral islands vulnerable to erosion, are found several genera of strand trees and shrubs that can be of value in stabilizing beaches. These include species in the genera Messerschmidia, Casuarina, Scaevula, and Terminalia.

(2) In intertidal freshwater areas such as those found far inland in the Chesapeake Bay and in rivers such as the James, the Cape Fear, and the Columbia, woody vegetation that would be useful in shoreline and levee stabilization include a number of willows (Salix spp), alders (Alnus spp.), cotton-woods (Populus spp.), and such large trees as American sycamore (Platenus occidentalis) and willow oak (Quercus phellos). Black willow (Salix nigra) and sandbar willow (Salix interior) are pioneer species on beaches and dredged material deposits in freshwater/intertidal areas, and both can easily be planted on such sites to aid in stabilization. Plantings can be in the form of individual cuttings, wattling, matting, or willow fencing and can also be coupled with erosion control structures such as riprap or sandbags. Additional information on these techniques and plant species are available in EM 1110-2-5026, and in Allen and Klimas (1986), US Army Engineer Waterways Experiment Station (1986), and Schiechtl (1980).

(3) In intertidal saltwater areas such as those found in the Intra-coastal Waterway and along barrier islands and shorelines, the primary tree species that can be used for stabilization in North America are mangroves. It should be noted that mangrove species are not winter-hardy north of central Florida and south Texas. In those temperature zones, mangroves will establish naturally if wave conditions are suitable. In many cases where plant establishment is important to shoreline stabilization, such as on the fringes of dredged material

islands, mangrove establishment takes place by a unique planting method. First, smooth cordgrass (Spartina alterniflora) is planted in the intertidal zones, and mangrove propagules (seed pods) are planted between the Spartina sprigs. The Spartina is used to provide initial stabilization and to provide a protective substrate for the mangrove seedlings while they establish root systems. Eventually, the young mangroves overtop the Spartina, and the shade from the mangrove trees kills the Spartina. The primary mangrove used in this process is black mangrove (Avicennia germinans), since it is the mangrove usually found mixed with natural stands of Spartina in Florida and other tropical areas. White mangrove (Laguncularia racemosa) is the other mangrove which often grows in early successional stages with black mangrove. Red mangrove (Rhizophora mangle) is the climax in many areas and grows further out into the water than the other two species. Thus, for many years it was thought that red mangrove was the pioneer species until studies showed that black and white mangroves were actually the pioneers, followed by red mangroves (Lewis and Lewis 1978).

(4) Three other woody species which have been introduced to North America that will tolerate semiflooded conditions and that will provide shore-line stabilization are the punk tree (Melaleuca quinquenervia), tuart tree (Eucalyptus gomphocephalus), and Chinese tallow tree (Sapium sebiferum). However, it must be emphasized that these three species can very easily proliferate on their own and will quickly become pest species. Punk tree is a major problem in south Florida where it was introduced for shoreline stabilization in freshwater areas. It has spread on its own and has invaded the Everglades where it is displacing native species. These species are not recommended for Corps sites.

(5) There are a number of woody species that are common to coastal shorelines of North America that tolerate salt spray but do not tolerate saltwater conditions. They grow well from the mean high tide line up to dune or beach crests and establish well on beach slopes. Any of these species can be planted to hasten maritime forest development along beaches, but none can be relied upon to stop erosion in the intertidal zone. These plants, listed below in no particular order of importance or ability to colonize shorelines, are:

(a) Pinus maritima (maritime pine).

(b) Scaevola plumieri (scaevola).

(c) Tamarix aphylla (athel tamrisk).

(d) Tamarix gallica (French tamrisk).

(e) Schinus terebinthifolius (Brazilian pepper tree).

(f) _Baccharis halimifolia_ (groundsel tree).

(g) _Juniperus silicicola_ (Florida red cedar).

(h) _Casurina equisetifolia_ (Australian pine).

(i) _Sabel palmetto_ (cabbage palm).

(j) _Myrica cerifera_ (wax myrtle).

(k) _Atriplex arenaria_ (orach).

(l) _Kostelelzkya virginica_ (salt marsh mallow).

(m) _Forestiera segregata_ (Florida privet).

(n) _Conocarpus erectus_ (buttonwood).

(o) _Myricanthes fragrans_(nakewood).

(p) _Psidium guajava_ (guava).

(6) All of these species can be propagated readily, and in many cases, plants are available from nursery sources such as commercial businesses and US Department of Agriculture Soil Conservation Plant Material Centers. All of them should be transplanted as small trees or seedlings onto the site requiring stabilization rather than trying to use seeds for propagation (Landin 1978, US Army Engineer Waterways Experiment Station 1978, EM 1110-2-5026).

(7) The use of marsh or woody vegetation to stabilize shorelines and levees in lieu of or in conjunction with engineering features such as riprap can reduce costs of stabilization and will generally enhance the aesthetics of the eroding area. In areas where clean beaches are the desired result of the shoreline project, however, vegetation will not be readily accepted by users. Also, very heavy use of beach areas by recreationalists will retard or destroy any planted vegetation used for beach or dune stabilization, and such areas may have to be fenced or posted off-limits until plants are well established (EM 1110-2-5026).

e. Role in Shore Protection. Dune systems have two primary functions in shore processes. First, they act as a levee to prevent the inland penetration of waves and storm surges during some storm events. Second, they provide a reservoir of sand to nourish eroding beaches during storms.

(1) Overtopping. Assuming that the foredunes are not washed away, they prevent storm waters from flooding low interior areas (Figure 4-7). Large reductions in water overtopping are affected by small increases in the elevation of the foredune crest. For example, it has been estimated

that a l-meter (3-foot)-high dune on Padre Island, Texas, would prevent overtopping from water levels accompanying storms with an expected recurrence interval of five years (US Army Engineer Waterways Experiment Station 1984).

(2) Sand reservoir.

(a) During storm, erosion of the beach generally occurs and the shoreline recedes. In a sense, the dynamic response of a beach under storm attack is a sacrifice of some beach width to provide material for an offshore bar (Figure 4-8). This bar reduces the shoreline erosion. Dunes can reduce the amount of beach loss occurring during a particular storm event by contributing sand to the upper beach and offshore bar system.

(b) Recent investigations have estimated the volumes of sand eroded from beaches during storms. Losses from erosion during single storms on the shore of Lake Michigan, on Jones Beach, New York (Everts 1973), and on Mustang Island, Texas (Davis 1972), have been estimated to be as high as 14,000, 17,000, and 31,000 cubic meters per kilometer (29,000, 35,000, and 65,000 cubic yards per mile), respectively. These volumes are probably representative of temporary storm losses because much of the eroded sand usually is returned to the beach by wave action soon after the storm. Birkemeir (1979) studied poststorm changes on Long Beach Island, New Jersey. He found that about one half of the sand that eroded from the beach during the storm was returned to the beach within two days. Volumes of sediment equivalent to those eroded during the storm were trapped and stored by natural processes in foredunes adjacent to the beach at several locations. Foredunes constructed on Cape Cod, Massachusetts (Knutson 1980), Ocracoke Island, North Carolina (Woodhouse, Seneca, and Broome 1976), and Padre Island, Texas (Dahl et al. 1975), contained 60,000, 80,000, and 120,000 cubic meters of sand per kilometer 135,000, 185,000, and 275,000 cubic yards per mile) of beach, respectively.

f. Physical Consideration.

(1) Shore erosion.

(a) On an eroding coast, a stabilized dune will slow but not prevent erosion. Dunes can serve effectively as barriers to high-energy surf, but eventually storm waves will undermine or overtop the dunes with a subsequent net loss of sediment from the original dune. The life span of a particular foredune line is a function of the rate of shoreline erosion, dune height, and width. Large, well-developed dunes commonly withstand moderate storms and often relatively severe ones. But where beach erosion is rapid, artificial stabilization will result in dunes of limited size and short life span. Stabilization of dunes on such a coast will provide only temporary protection to backdune structures or facilities.

Figure 4-7. Dunes under wave attack, Cape Cod, Massachusetts (courtesy of Stephen P. Leatherman)

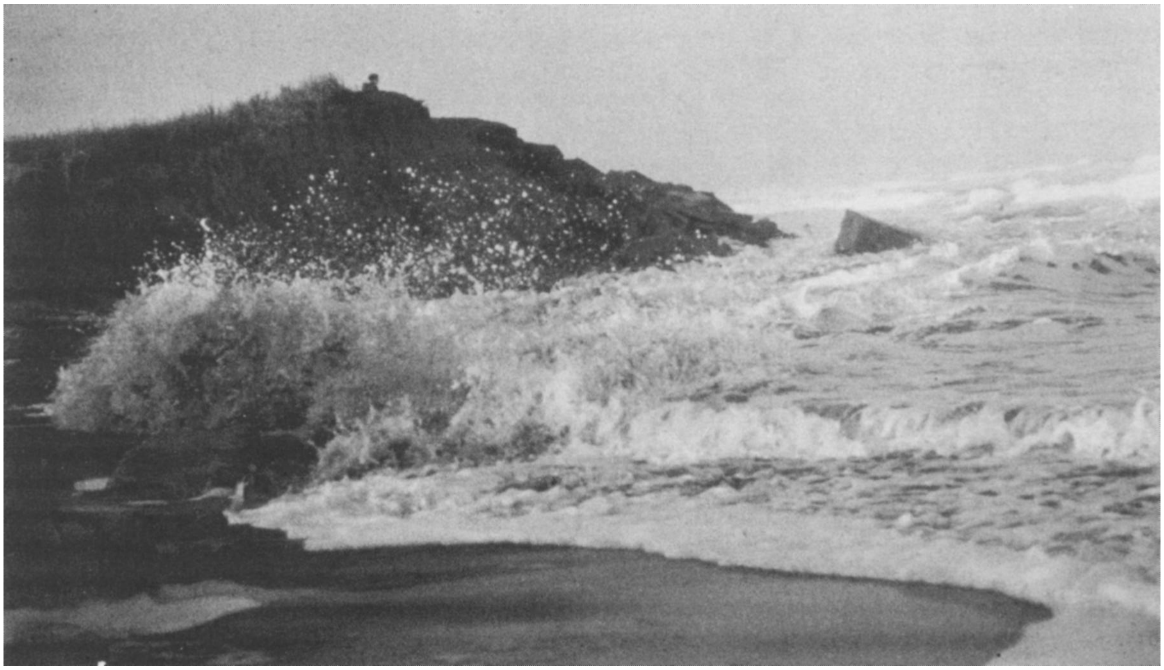

Figure 4-8. Dunes erosion during severe storm, Cape Cod, Massachusetts (courtesy of Stephen P. Leatherman)

(b) The impact of dunes on beach processes has been reviewed in detail by Leatherman (1979a-a). Leatherman concluded that much of the material removed from the dune and beach reforms as one or more nearshore bars. Wave reflection off the nearshore bars causes diminution of the incident waves and eventually reduces dune erosion. Seaward development of nearshore bars during high-wave storm events result in a dissipative surf zone (Figure 4-9) with shoreward decay of incident waves (Wright et al. 1979). The nearshore bar exhibits a cyclic behavior. During fair-weather conditions, the bar migrates landward and after several weeks may merge with the foreshore. Additional information on the process of onshore bar migration after a storm event due to decreasing wave power is provided by Short (1979). It should also be noted that major storms and high waves tend to flatten the foreshore profile rather than steepen it.

(c) Erosion of dunes by storms is a natural occurrence. This material provides a source of sand for the beach. As offshore sediments return to the foreshore to reestablish the original beach profile, onshore winds return sediment to the eroded dune. Whether or not the dunes revert to their former size depends on the local sand budget. If more sediment is leaving a local coastal zone than entering it, dunes will exhibit continual erosion. Where dunes are breached or undermined, dunes will reestablish naturally but usually landward of the original dune line. Sea-level rise may also cause dune erosion. If an adequate supply of sediment is available, the dune may migrate landward with the shoreline (Bruun 1983).

(d) High dunes, natural or artificial, reduce foreshore erosion during storms because much of the dunes and is transported seaward, ultimately to an outer bar and thereby further dissipating wave energy. This process does not appear to effect long-term erosional or depositional trends on the shoreline. Rather, stable dunes buffer rapid changes in the beach associated with the severe storm events.

(2) Barrier island migration.

(a) Barrier islands are elongated islands that mostly parallel the mainland shores of the Gulf of Mexico and Atlantic coasts. The coastal plain and continental shelf adjoining barrier islands are broad and gently sloping. In response to sea-level rise the coastal plain is being submerged. If barrier islands were to occupy a fixed position on the continental shelf, they eventually would be submerged by sea rise. It has been postulated that barrier islands migrate landward up the continental shelf maintaining a relatively constant elevation with respect to sea-level rise. Retreat of the seaward shore is accomplished by shore erosion, while the landward shore is extended by sediments transported between and around the island by tidal inlets and sediment transported over the islands by overwash and wind.

Figure 4-9. Dissipative surf conditions during Storm, Outer Banks, North Carolina

(b) Considering that the objective of most dune stabilization projects is to reduce the frequency of overwash and flooding, barrier island migration is an issue that should be addressed on a case-by-case basis. Though overwash processes have been shown to dominate some narrow barrier islands, most barrier islands appear to be too wide to migrate as a result of overwash. For example, the North Carolina barrier islands have narrowed, not migrated, over the past 130 years (Everts et al. 1983). Beach sands carried by overwash rarely reach the lagoonal side of most barrier islands, though after the barrier island narrows to a critical width, ovewash events may contribute to landward migration. Leatherman (1976) determined the critical maximum width for overwash based on an effective transport mechanism on Assateague Island, Maryland, to be between 100 and 200 meters (300 to 600 feet).

(c) The impact of small, localized dune-stabilization projects on barrier migration does not warrant extensive discussion. The beach grass planting techniques used to encourage dune growth mimic the natural dune building processes that are at work on all barrier systems. Typically, these techniques are used only when there is a need to protect existing man-made structures. Where such development exists, the absence of stable dune systems can often be attributed to human activities.

(d) The issue of barrier migration, however, may be raised when dune--stabilization efforts are employed to restabilize areas damaged by storm events. In this case, it should be recognized that the project, if successful, will accelerate dune establishment and will for a period of time reduce the frequency of overwash. The influence of this reduction in overwash, if any, on barrier island migration often will depend upon the type of barrier being stabilized. Upon relatively broad barriers, where the likelihood of an overwash traversing the entire barrier is remote, dune stabilization will have little impact on barrier migration. As noted earlier, most United States barriers are too broad for overwash to significantly effect their migration. On narrow, eroding barriers, overwash frequently will be critical to migration processes.

g. Water Quality Considerations. Dune sediments are composed of fine to coarse sands. Most coastal dune sediments are indirectly derived from reworked fluvial (river) and/or glacial material. Typically, dunes are nutrient poor and lack an organic component. Consequently, rainfall rapidly infiltrates the sediment, permitting little evaporation or surface runoff. Dune sands are a reservoir of fresh water and an aquifer for domestic water supply. Dune stabilization, by increasing the frequency and extent of dunes, can only enhance this resource.

h. Impacts of Human-Built Dunes.

(1) Dune vegetation. Human efforts to stabilize coastal dunes usually entail planting aggressive, perennial beach grasses in monospecific stands. These planted species remain dominant on the dune for many years after planting. Dahl and Goen (1977) found that when a dune forms naturally with the pioneering plants available to the area, some species remain from previous successional stages and a natural component of the mature dune plant community. However, planting of beach grasses bypasses some of the pioneering successional stages, resulting in rapid plant growth and dune development but in less plant diversity on the mature, planted dune. This lack of plant diversity is typically an unavoidable result of human-built dunes. Plant diversity is associated with slow and protracted dune development, which is contrary to the objectives of most dune stabilization projects. Cowan (1975) and others have conducted experiments on stabilizing dunes using a greater diversity of native species. However, because these native species are not commercially available and often require specialized treatment, such as hydromulching and irrigation, attempts to stabilize dunes in this manner are very costly.

(2) Secondary dune vegetation impacts.

(a) Some investigators have cautioned, based upon experiments conducted on the Outer banks of North Carolina, that dune stabilization projects may adversely impact coastal plant communities (Dolan, Godfrey, and Odum 1983, Godfrey and Godfrey 1973). They observed that high, continuous dunes form an effective barrier to stormwaves, reducing the amount of salt spray and preventing overwash. This protection of the secondary dune area can encourage the invasion and growth of shrub communities. At Cape Hatteras, North Carolina, continuous impenetrable thickets 3 to 5 meters (10 to 20 feet) high have formed in the lee of protective dunes. The National Park Service has resorted to controlled burnings to counter these changes. The excessive development of shrub communities in association with dunes is not an ecological issue in New England (Zaremba and Leatherman 1984) and has not been reported to be a problem in other regions. The shrubs do provide some benefit by providing storm erosion protection and wildlife habitat.

(b) The vegetative changes associated with artificial development of dunes are often considered ecologically beneficial. For example, plantings were made on Padre Island, Texas, following Hurricanes Carla and Beulah in 1967. Much of the island was unvegetated, hurricane-planed backshore and barren, migrating dunes. By 1976 the island's soil adjacent to the planted dunes was measurably less arid than other portions of this south Texas island (Figure 4-10). The mesic (moist) microclimate bayward of the planted dunes is believed to be due to the damming effect provided by the resultant dunes. These dunes retain rainwater in the mid-dune area, providing a more favorable habitat.

(c) The development of new dunes by planting or other means will change the microclimate of areas adjacent to the developing dunes. Whether or not these changes are viewed as ecologically positive or negative will depend upon the local importance and abundance of the habitats which are to be modified. Areas that are frequently stressed, by ovewash for example, either lack vegetation or are colonized by a limited number of grasses and forbs. Developing dunes provide a measure of stability to adjacent areas, reducing flooding and salt spray. This stability makes the environment suitable for a greater diversity of plant species. If stable for a sufficient length of time (10 to 50 years), shrubs will invade and later dominate the plant community (Dolan, Godfrey, and Odum 1973, Zaremba and Leatherman 1984). If stability continues, mature forests can develop in 50 to 100 years.

(d) The shrub and forest communities represent an improved habitat for terrestrial animals and many bird species, principally song birds, though herons and egrets also use coastal shrubs for nesting. Conversely, bare sand and grass areas on the coast are the primary nesting sites for many colonial nesting birds, particularly gulls and terns.

(3) Back barrier salt marsh impacts.

(a) The coastal salt marshes of the United States are considered to be a major environmental resource. They are important contributors to the primary production of the coastal zone and are essential nursery grounds for sport and commercial fishery species. Some researchers contend that

Figure 4-10. Vegetation landward (left on photo) of artificially stabilized dune, Padre Island, Texas (courtesy of Bill E. Dahl)

dune stabilization can impede the development of salt marshes on the back side of barrier islands (Godfrey and Godfrey 1973). This contention is related to sediment overwash providing substrate for the development extension of the marsh into the bay or sound. If overwash does not occur, the marshes slowly erode.

(b) Salt marshes are intertidal plant communities found on the Atlantic and Gulf coasts and, to a lesser extent, on the Pacific coast. Two processes are of particular importance in creating shallow, marine environments in which marshes may establish: flooding due to sea-level rise and/or subsidence of land, and sediment deposition. Salt marshes are often associated with deltas. The Mississippi River delta is a spectacular example of the constructive impact of sediment deposition on marsh development. This delta system represents nearly half of our nation's coastal marshes. Deltas also are responsible for the development of the majority of Pacific coast marshes.

(c) On much of the Gulf and Atlantic coasts, however, deposition of barrier island sediment is important to marsh development. Active and remnant flood-tidal deltas behind these barriers are commonly the focus of marsh development (Godfrey and Godfrey 1973) as shown in Figure 4-11. On some barriers, marshes are altogether absent except where there is evidence of inlet activity (Leatherman and Joneja 1980). Overwash may have either a negative or positive impact on marshes. When stable marshes are present landward of the barrier, overwash events may destroy the marsh through burial or change its ecological character by raising its elevation (Zaremba and Leatherman 1984). Conversely, overwash may widen a narrow eroding marsh or may encourage the growth of new marshes on barren areas by creating a broad, gradually sloping, intertidal plain (Godfrey and Godfrey 1974).

(d) To fully evaluate the potential impact of a particular dune stabilization project on marsh development, two factors must be considered. First, back-barrier marshes will only be impacted when the entire width of the barrier is traversed by overwash or the entire barrier is breached by an ephemeral inlet. Therefore, marsh impacts will be a concern only where events of this magnitude can be reasonably expected to occur within the anticipated life of the project. Second, the current condition of the marshes landward of the barrier should be evaluated. The impact on marsh development will be a project issue if barren shore or eroding marshes are present in the back—barrier area.

Figure 4-11. Salt marshes landward of barrier island system, Murrells Inlet, South Carolina

i. Recreational Considerations.

(1) In general, coastal dunes have a positive impact on recreational

use of the shore. Dunes enhance beach recreational experience by providing shelter from the wind and screening structures and facilities from the beach view. However, sometimes high dunes can obstruct the desirable view of the beach for people using inland facilities.

(2) Recreational use of dunes, however, can seriously impact dune stability. Pedestrian traffic to and from the beach often damages or destroys vegetation along frequently used paths. Knutson (1980) observed a dune crossover path on a developing dune over a five-year period. Although the dunes adjacent to the path increased in elevation by more than one meter (3 feet), the elevation of the path remained constant. Dune areas in which vegetation has been disturbed may deflate rapidly. Field surveys on Assateague Island, Maryland, documented pathway deflation rates of more than one-half meter (2 feet) per year (Leatherman 1979b). These weakened areas of the dune system are the first areas to be overwashed during severe storms. Beach dune walk-over structures can be placed to lessen the Impact of pedestrian traffic (Coastal Engineering Research Center 1981).

(3) Off-road vehicle (ORV) traffic can also severely impact developing dunes. The effect of ORV activity on American beach grass on Cape Cod showed that low levels of activity (less than 175 passes) were sufficient to cause maximum damage to plants (Brodhead and Godfrey 1979). Fewer than 50 passes were shown to preclude seaward growth and development of the foredune system in some cases.

(4) Sand fences are often used to lessen the impact of foot traffic on the dune. Fences can be used to confine and direct traffic to designated crossover areas. These crossovers can be relocated periodically and impact areas can be replanted with beach grass. If ORV traffic is present, wooden ramps should be built over dune lines. Maintenance and repair must be a continuing effort in these situations.

j. Aesthetic Considerations.

(1) There are several features of human-built dunes which make them visually different from natural dunes, at least during the early stages of dune development. Natural dunes are formed by a series of chance events. They begin as small individual hummocks, usually of assorted shapes and sizes. The hummocks may coalesce over time, and the resultant dune will be irregular in elevation and in its location with respect to the shore. Regardless of stabilization procedure, human-built dunes tend to be linear (Figure 4-12). Dunes can be designed with a zigzag or other patterns, but for practical and economical reasons they usually are not. First, straight dunes require the least effort and materials to construct. Second, if an irregular pattern were used on an eroding shoreline, the portion of the dune closest to the shore would be the first area to erode. The flood protection provided by a dune system is limited to the protection provided by the weakest portion of the system. The same line

of thinking can be used to discourage the use of an irregular dune crest elevation. Because of these considerations, human-built dunes typically will be more regular in appearance and more continuous than natural dunes.

(2) The human-built dunes can be made to conform to natural dune contours in other respects. The selection of stabilization technique may influence the final shape of the dune. Knutson (1980) observed in Cape Cod experiments that planted dunes produced lower and wider dunes than fence-built dunes. In North Carolina, researchers found that decreasing plant spacing both landward and seaward from the dune crest increased dune width and reduced the seaward slope of the dune from about one on ten to one on twenty (Savage and Woodhouse 1968).

Figure 4-12. Linear shaped, planted dune system, Outer Banks, North Carolina (courtesy of R. P. Savage)

k. Cultural Considerations. As a shore protection measure, dune stabilization will often protect onsite cultural resources. However, if dunes are created by mechanical methods, potential exists for onsite equipment and traffic damage to cultural resources. Because of the dynamic nature of beach and dune systems (cyclical erosion and deposition), cultural resources are not a common feature in dune stabilization project areas.

l. Environmental Summary.

(1) Environmental design. When beach grasses are used to create and

stabilize coastal dunes, human-built dunes can be developed which are aesthetically and biologically similar to natural dunes. Dune slope, alignment, and plant diversity can be controlled through the selection of an appropriate planting design. In most cases, the planted dune will have a greater diversity of both plants and animals than the unstable sand environment which preceded it. The use of construction equipment to build dunes will generally increase potential for environmental impacts. Vehicular traffic can damage or destroy coastal vegetation. Controlling equipment traffic patterns, constructing sand fences and walkovers, and replanting damaged areas can mitigate these impacts.

(2) Additional environmental considerations.

(a) Short-term impacts. During construction, coastal plant communities can be disturbed by equipment and human traffic.

(b) Long-term impacts. Small, localized dune-stabilization efforts, particularly the planting of dune vegetation, can usually be considered as conservation measures. Dune-building techniques are only used when there is a need to protect existing facilities. Where such development exists, the absence of stable dunes can often be attributed to human activities, hence dune building can be a restorative action. Environmental impacts are not likely to be a major consideration even for relatively extensive dune-stabilization projects in mainland coastal areas. However, major efforts to build continuous dunes on barrier islands to provide protection to mainland areas from major storms and hurricanes will require more serious consideration. Projects of this magnitude may potentially alter the geological and ecological characteristics of the barrier system. Major dune-stabilization projects along a barrier system should be preceded by an investigation of the role that the dunes and the physical processes modified by dunes play in the overall dynamics of the system.